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(54) **Vacuum pump**

(57) The invention concerns a vacuum pump comprising a casing (2) in which gas pumping stages are housed, an suction port for sucking the gases to be pumped, and an exhaust port (4) of the pumped gases, wherein upstream of the gas suction port there is provided a heat exchanger (21) for freeze-trapping undesired gases, and said heat exchanger (21) is directly in contact with the cold end (22) of a closed circuit cryogenic assembly (30) of the Joule-Thomson type, in which a refrigerant gas mixture is circulated.

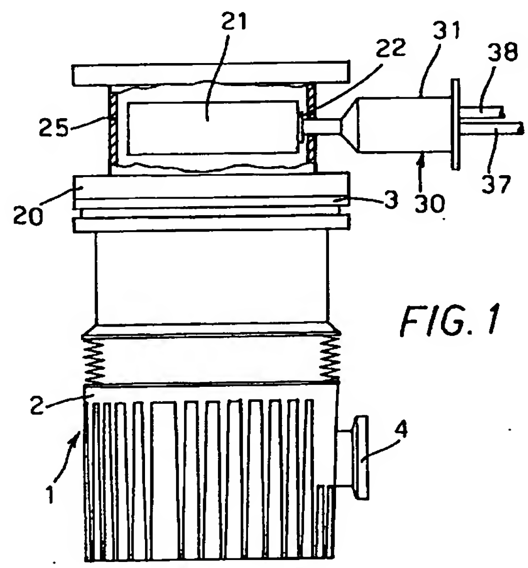

FIG. 1

EP 0 819 856 A1

Description

The present invention relates to a vacuum pump. More precisely the invention is concerned with a vacuum pump of the turbomolecular type comprising a so-called cryogenic trap.

A vacuum pump substantially comprises a casing containing a number of gas pumping stages formed by rotor disks secured to the rotatable shaft of the pump, cooperating with stator rings attached to the pump casing.

The casing is further provided with a gas inlet or suction port for sucking the gases to be pumped and an exhaust port for discharging the pumped gases.

Vacuum levels in the order of 10^{-8} Pa can be obtained by Using a vacuum pump of the turbomolecular type.

A turbomolecular vacuum pump is disclosed in EP-A-0 445 855 in the name of the present applicant.

It is known that undesired vapors such as oil, water, carbon dioxide or solvents vapors can be included in the gas to be pumped through a vacuum pump.

This implies a decrease of the pump performance and the risk of damaging the pump components.

In order to solve the above mentioned drawback generally a selective pumping device is disposed upstream of the suction port of the vacuum pump, with the purpose of trapping one or more of the vapors such as oil, water and solvent vapors.

Among the selective pumping device commonly employed for the above purpose, there are known the so-called cryopumps i.e. equipped with freeze-trapping devices in which the above mentioned gases are condensed upon reaching a temperature in the order of 150°K.

An example of a turbomolecular pump provided with a freeze-trapping device is disclosed in US-A-4 926 648.

US-A-4 926 648 discloses a turbomolecular pump comprising a heat exchanger located within the suction port of the gas to be pumped and upstream of the pumping stages of the turbomolecular pump.

Such heat exchanger is connected with a refrigerator outside the turbomolecular pump, through a double pipe, i.e. a delivery and a return pipes, adapted to supply a very low temperature refrigerant fluid from the refrigerating device to the heat exchanger and vice-versa.

More precisely, through the delivery pipe the "cold" refrigerant from the refrigerator is supplied to the heat exchanger inside the pump and then, through the "warm" return pipe, the refrigerant fluid is returned to the refrigerator.

However the solution teached in the above mentioned document has the drawback of requiring a twofold connecting pipe, located between the refrigerator and the heat exchanger, and since this pipe must be thermally insulated its length must be as short as possible.

This involves an increase of both the manufacturing cost and the system complexity, and prevents the use of a twofold connecting pipe of a desired length.

A second example of a turbomolecular pump equipped with a cryogenic trap is disclosed in US-A-5 062 271.

US-A-5 062 271 discloses a turbomolecular pump comprising a heat exchanger disposed inside the suction port of the gas to be pumped.

Such heat exchanger is associated with a single-stage Gifford-McMahon cycle helium refrigerator located adjacent the suction port of the turbomolecular pump and connected to a separate compressor unit through a twofold (delivery and return) pipe.

One of the major advantages when using a Gifford-McMahon refrigerator is that the delivery and return pipes of the refrigerant are "warm" and consequentely do not require a thermal insulation.

The apparatus disclosed in the last mentioned document has nevertheless the shortcoming of requiring a Gifford-McMahon refrigerator which notoriously comprises moving parts and is particularly complex and expensive, and requires a helium refrigerating mixture.

US-A-5 337 572 discloses a closed circuit refrigerator provided with a single stage rolling piston compressor for obtaining low temperatures in the range from 65°K to 150°K.

The apparatus disclosed in US-A-5 337 572 permits to obtain very low temperatures on small surfaces and is particularly applicable in the field of cryosurgery instruments.

In applications where turbomolecular pumps are used together with cryopumps, the temperature to be reached on the cryopump surface is generally above 150°K.

At temperature lower than 150°K the cryopump would trap other gases having a larger molecular weight than that of water vapor, and such gases should be removed from the turbomolecular pump, with a consequent quick exhaustion of the pumping capability of the cryopump.

Particularly in presence di corrosive gases, such as those employed in the manufacturing of integrated circuits, the purpose of the cryogenic pumping stage located upstream of the inlet port for sucking the gases into the turbomolecular pump, is to remove only the water vapor, if present, from the pumped gas mixture, while the other gases are to be removed by the turbomolecular pump.

Moreover the design of the condensing surface in a cryopump has to provide for a sufficiently large area for intercepting as much as possible of the water vapor present in the sucked gas mixture.

It is therefore an object of the present invention to realize a vacuum pump provided with a cryogenic trapping device that is free from the shortcomings of the prior apparatuses, and that employs a single compres-

sion stage refrigerator.

This object of the present invention is accomplished through a vacuum pump as claimed in claim 1.

Further characteristics and advantages of the invention will become evident from the description of a preferred but not exclusive embodiment of a vacuum pump, illustrated as an example only and without limiting purposes in the attached drawings in which:

Figure 1 is a partially sectional front view of a vacuùm pump'in accordance with the invention;
Figure 2 is a block diagram of a refrigerating circuit used in a vacuum pump according to the invention;
Figure 3a is a perspective view of a heat exchanger according to a first embodiment of the invention;
Figure 3b is a perspective view of a heat exchanger according to a second embodiment of the invention;
Figure 3c is a partial sectional front view of a heat exchanger according to a third embodiment of the invention;
Figure 4a is a sectional view of the cryogenic assembly according to a first embodiment of the invention;
Figure 4b is a sectional view of a cryogenic assembly according to a second embodiment of the invention;
Figure 5 is a sectional view of a vacuum pump of the turbomolecular type improved in accordance with the known art.

Figure 1 illustrates a vacuum pump 1 of the turbomolecular type comprising a casing 2, an axial inlet or suction port 3 for the gas to be pumped, and a radial exhaust port 4 of the pumped gases.

As better shown in Figure 5, a plurality of pumping stages 10, 10a, formed by rotors 11, 11a secured to a rotatable shaft 13, and alternate stators 12, 12a are provided inside the casing 2 of the turbomolecular pump.

The known turbomolecular pump shown in Figure 5 has a special design comprising one or more pumping stages 10a with a tangential flow, in addition to conventional pumping stages 10 with an axial flow.

Each tangential flow stage 10a comprises a rotor 11a formed as a flat disk and associated with a coplanar annular stator 12a spaced from each other so as to form an annular free channel 14 therebetween, with the pumped gas flowing along a tangential path in the direction shown by the arrow E in Figure 5, corresponding to the counterclockwise direction of rotation of the shaft 13, indicated in Figure 5 by the arrow C.

A baffle 15 closes the channel 14 between a suction opening 17 and an exhaust opening 18, provided in an upper closing plate 16 and in a lower closing plate 19, respectively.

Returning to Figure 1, a flanged collar 20 is fastened upstream of the plurality of pumping stages 10, 10a and houses a heat exchanger 21.

The flanged collar 20 and the casing 2 are axially aligned and can be formed as an integral component.

Thus the casing is divided into a first portion containing the pumping stages 10, 10a and a second portion containing the heat exchanger 21.

In a first embodiment of the invention illustrated in Figure 3a, the heat exchanger 21 is preferably formed by a thin wall cylindrical element that is substantially coaxial to the flanged collar 20, and laterally secured to the cold end 22 of a cryogenic assembly 30 that is part of a closed circuit refrigerating system.

The cryogenic assembly 30 is preferably of the Joule-Thomson type, in which the temperature of a compressed gas that is allowed to expand decreases as a function of the energy absorbed to overcome the molecular coesion forces.

With reference to Figure 4a, said cryogenic assembly 30 is housed within a high vacuum casing 31 and comprises a (heat transfer) coil 32 in which a refrigerant flows, made up by a first high pressure inlet section 33, defining the condensing unit of such cryogenic assembly, a throttling portion 34, disposed downstream of said first section 33, at the outlet of which the gas mixture is quickly cooled by letting it to expand, an intermediate section 35 in contact with the cold end 22 of the cryogenic assembly 30, and a low pressure outlet section 36, defining the evaporating unit of such cryogenic assembly 30.

The casing 31 housing the cryogenic assembly 30 is partially located outside the flanged collar 20, and its cold end 22 is disposed within the flanged collar 20 and insulated by a high vacuum gasket fitted in the wall 25 of said flanged collar 20.

Through a high pressure delivery pipe 37 and a low pressure return pipe 38, the cryogenic assembly 30 is connected to a compressor 39 of the refrigerating circuit illustrated with more details in Figure 2.

The refrigerating circuit schematically illustrated in Figure 2 comprises a single stage compressor 39 including an oil lubricated rotating piston, to which a refrigerating mixture of gas and oil is fed through a low pressure pipe 38.

The compression ratio attainable by the compressor 39 is preferably of 5:1 and the volumetric efficiency of said compressor is higher than 50%.

Said low pressure refrigerating mixture of gas and oil is compressed to a high pressure by compressor 39 and then is delivered to the cryogenic assembly 30 through the high pressure pipe 37.

Downstream of the compressor 39 there is located an oil separator 40 embodied as a simple gas-liquid filter adapted to separate the oil from the high pressure refrigerating mixture and to return the oil to the low pressure pipe 38, through a return pipe 42.

In the schematic diagram of Figure 2 there is further shown an air or water cooler 41, preferably downstream of the oil separator 40, for cooling the compressed gas mixture, after the heating thereof caused by compression in the compressor 39, and a dehydrator 43 for

removing the condensate residuals from within the pipes.

The compressed mixture that has been cooled in the cooler 41 is delivered to the cryogenic assembly 30 through the section of the high pressure 37 pipe that is located downstream of the cooler 41.

From the above it is evident that both the pipes 37 and 38 are "warm" and do not require a thermal insulation whereby their length can be as long as desired.

In accordance with an alternative embodiment, in the heat exchanger 21' shown in Figure 3b, the axial extension of the cylinder wall forming the heat exchanger 21' is maximum at the proximal portion 23 at which the cold end 22 is secured, and minimum at the distal portion 24 diametrally opposed to the former. The axial extension of the wall linearly decreases from the securing portion 23 to the diametrally opposed portion 24.

The variable axial extension of the surface in the heat exchanger 21 is provided for compensating the temperature gradient that unavoidably is generated - because of the radiative heat - between the proximal portion 23 secured to the cold end 22 and the distal portion 24 of the heat exchanger 21, such gradient effecting the gas condensing capability.

It is known that the condensing capability depends on both the temperature of the cold surface and the extension of such cold surface.

Therefore, by increasing the surface in correspondence of the proximal (colder) portion 23, a more uniform spatial distribution of the temperature on the surface of the heat exchanger 21' is achieved.

With reference to Figure 4b there is illustrated a different embodiment of the cryogenic assembly in which the high pressure refrigerant delivery pipe 50 is disposed within the return pipe 51 of the refrigerant and coaxially thereto.

The inner pipe 50 terminates with a throttling portion 52 in correspondence of the expansion chamber 53 terminating the outer return pipe 51.

In the embodiment shown in Figure 4b the high pressure delivery pipe 50 is in thermal contact relationship with the return flow of the expanded refrigerating gas mixture that is at a lower temperature and contributes to the cooling of the delivery pipe 50.

The outer diameter of the assembly formed by the delivery and return coaxial pipes is about 1 cm, and its overall length is of a few meters.

In order to reduce the tube overall dimensions, the tube is wound to form a coil with only the cold end 54 protruding from the flanged collar, and fitted upstream of the suction port of the vacuum pump, through a high vacuum gasket.

In this embodiment the heat exchanger acting as a cryogenic pump only comprises the cold end 54 of the cryogenic assembly.

This solution can be employed also in combination with cryogenic assembies of different type, particularly of the type illustrated in Figure 4a, and is advantageous since it is simpler to be manufactured and eliminates every hindrance to the gas flow within the flanged collar.

Figure 3c illustrates a third embodiment of the heat exchanger in which the heat exchanger 61 is directly formed by two coaxial pipes, of the type illustrated in Figure 4b, helically wound and partially housed within the flanged collar 20'.

A first section 66 of the coaxial pipes defining the heat exchanger 61 is helically wound around an axis substantially coincident with the pump rotation axis, and is operatively connected through an intermediated and shaped section 64 to a second section 62 of said coaxial pipes, helically wound around a substantially radial axis and sealingly housed in a high vacuum casing 63 that is externally secured to the flanged collar 20' and open towards the inside of the flanged collar 20' through a window 69 formed in the flanged collar 20'.

The second helical section 62 protrudes from the casing 63 through a high vacuum gasket in the wall 65 of casing 63 and is connected to the delivery and return pipes 37 and 38 of the closed circuit cooling system described with reference to Figure 2, through the delivery and return pipe ends 67, 68, respectively, that constitute the inner and the outer pipes in the coaxial structure.

This embodiment is shown in Figure 3c and is advantageous in that the helical pipe defining the heat exchanger 61 can be easily shaped in accordance with the inner geometry of the flanged collar 20' housing the heat exchanger.

Moreover the casing 63 can be opened towards the inside of the flanged collar 20' since the vacuum created within the inside of the flanged collar 20' has sufficient thermal insulating capabilities.

Preferably the mixture of gases used in the cooling circuit of the present invention comprises a combination of the following gases: nitrogen, methane, ethylene, propane and isobutane.

In order to obtain the optimum temperature for condensing the water vapor, in the disclosed cryogenic cycle a gas mixture comprising 0.36 of nitrogen, 0.20 of methane, 0.12 of ethylene, 0.20 of propane and 0.12 of isobutane has been advantageously employed.

However mixtures containing nitrogen, argon and/or methane in amounts comprised either between 20% and 45% for a single component, or between 20% and 60% in any combination whatsoever, and at least two other gases selected from ethane, ethylene, propane, isopentane and isobutane were found to be equally effective for achieving the desired temperatures.

Claims

1. A vacuum pump comprising:

   - a substantially cylindrical casing in which a first portion (2) and a second portion (20) are

defined;

- a plurality of gas pumping stages housed within said first casing portion (2) and formed by rotor disks (11, 11a) secured to a rotatable shaft (13) of the pump and stator rings (12, 12a) secured to said pump casing and cooperating with said rotor disks (11, 11a);
- a suction port (3) for sucking the gases to be pumped and an exhaust port (4) for discharging the pumped gases;
- a selective pumping stage of the cryogenic type located on the upstream side of said plurality of gas pumping stages;

characterized in that said selective pumping stage comprises a closed circuit refrigerating system of the Joule-Thomson type, in which system a compressed refrigerant gas mixture is circulated, that is cooled through expansion at the cold end (22) of said refrigerating system located within said second casing portion (20).

2. A vacuum pump as claimed in claim 1, characterized in that said refrigerating system comprises a Joule-Thomson cryogenic assembly (30) equipped with a heat transfer coil (32) for the flow of said refrigerant gas mixture, said coil (32) comprising a high pressure delivery section (33), defining the condensing unit of said cryogenic assembly (30), a throttling portion (34) downstream of said delivery section (33), at the outlet of which the gas mixture is quicly cooled through expansion, an intermediate section (35) in contact with the cold end (22) of said cryogenic assembly (30), and a low pressure return section (36), defining the evaporation unit of said cryogenic assembly (30).

3. A vacuum pump as claimed in claim 1, characterized in that it provides a heat exchanger (21; 21') formed by a thin-wall cylindrical member secured to said cold end (22).

4. A vacuum pump as claimed in claim 3, characterized in that the axial extension of the cylinder wall forming said heat exchanger (21') is maximum at the proximal portion (23) to which the cold end (22) is secured, and minimum at the distal portion (24) diametrally opposed in respect of the former, said axial extension linearly decreasing from said securing portion (23) to said diametrally opposed portion (24).

5. A vacuum pump as claimed in claim 1, characterized in that said refrigerating system comprises two coaxial pipes, a first inner delivery pipe (50) and a second outer return pipe (51) of the refrigerant gas mixture, said inner delivery pipe (50) terminating with an expansion chamber (53) formed inside said second outer pipe (51), for expanding said refrigerant gas mixture.

6. A vacuum pump as claimed in claim 5, characterized in that it comprises a first helically wound section (66) of said two coaxial pipes, located in said second casing portion (20), and operatively connected through an intermediated section (64) of said two coaxial pipes to a second helically wound section (62) of said coaxial pipes, located outside said second casing portion (20).

7. A vacuum pump as claimed in claim 6, characterized in that said first section (66) of coaxial pipes helically extends substantially around the pump rotation axis, and in that said second section (62) of said coaxial pipes extends substantially around a radial direction.

8. A vacuum pump as claimed in claim 1, characterized in that said refrigerating system comprises a single stage rolling piston compressor (39).

9. A vacuum pump as claimed in claim 8, characterized in that said refrigerant gas mixture comprises 0.36 of azoto, 0.20 of methane, 0.12 of ethylene, 0.20 of propane and 0.12 of isobutane.

10. A vacuum pump as claimed in claim 9, characterized in that the compression ratio of said refrigerant mixture of said compressor (39) is 5:1 with a volumetric efficiency higher than 50%.

11. A vacuum pump as claimed in claim 1, characterized in that said second casing portion (20) comprises a flanged collar axially mounted to and aligned with said first casing portion (2).

12. A vacuum pump as claimed in any of the preceding claims, characterized in that said vacuum pump is a turbomolecular pump.

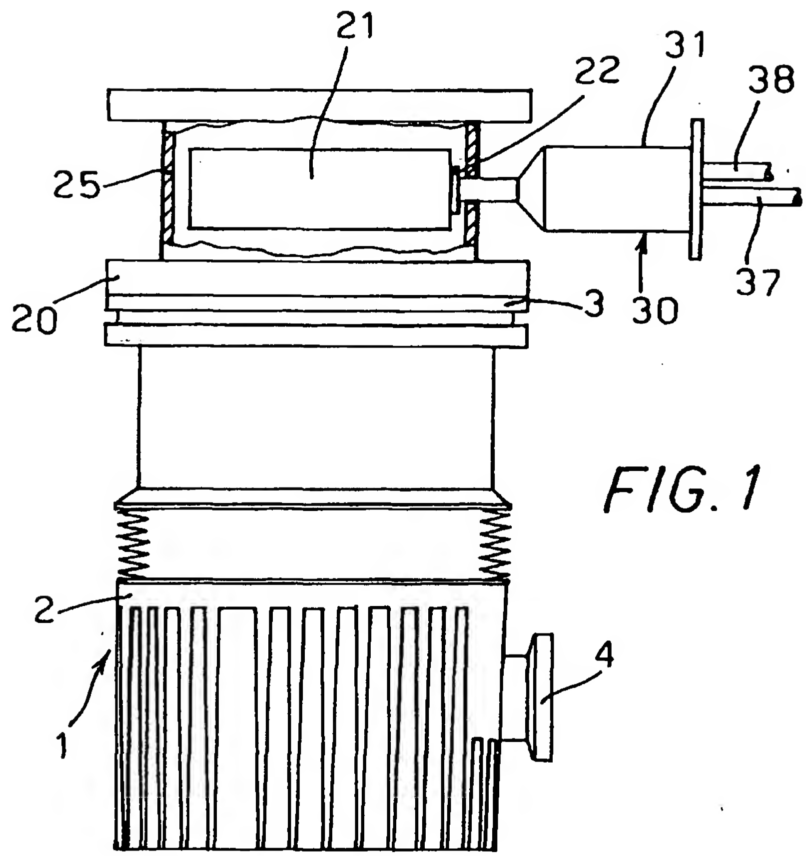

FIG. 1

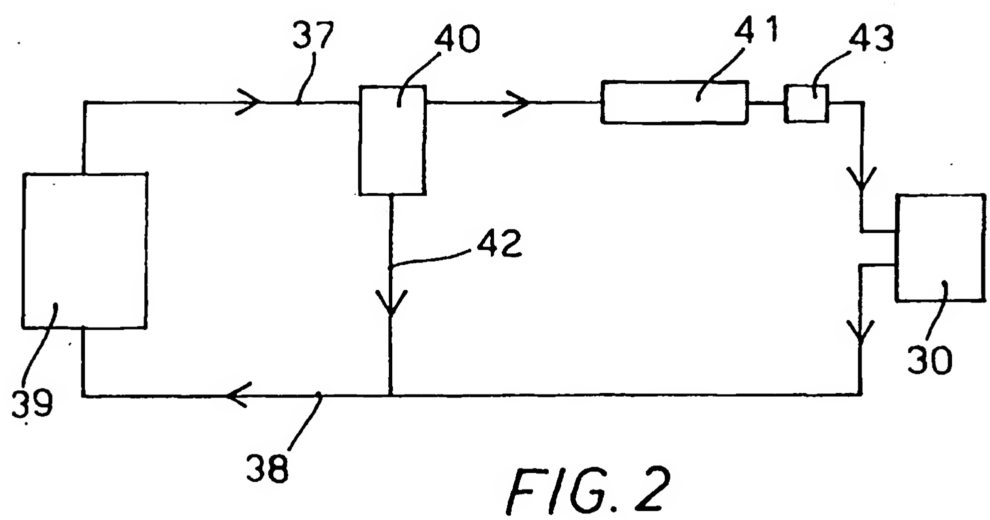

FIG. 2

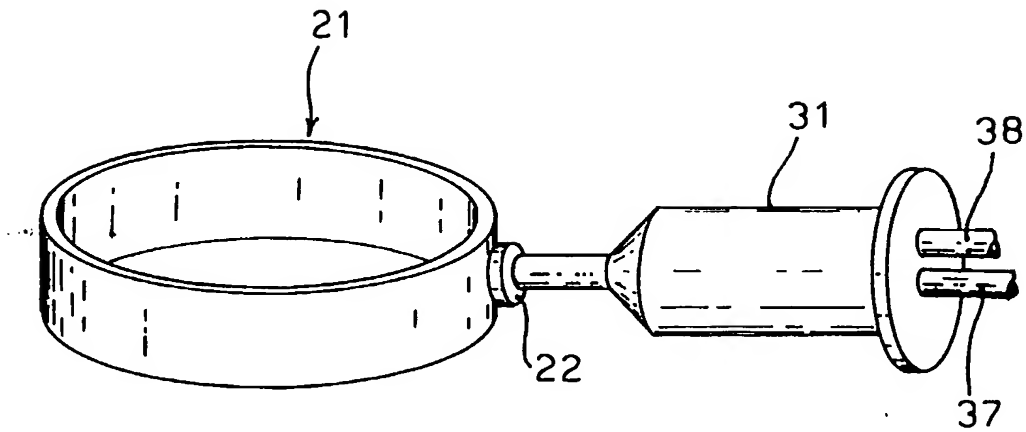

FIG. 3a

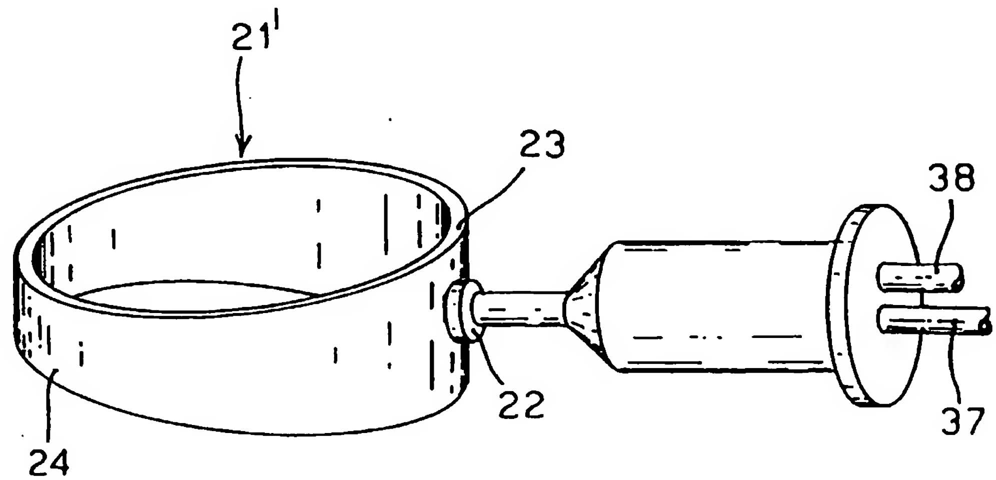

FIG. 3b

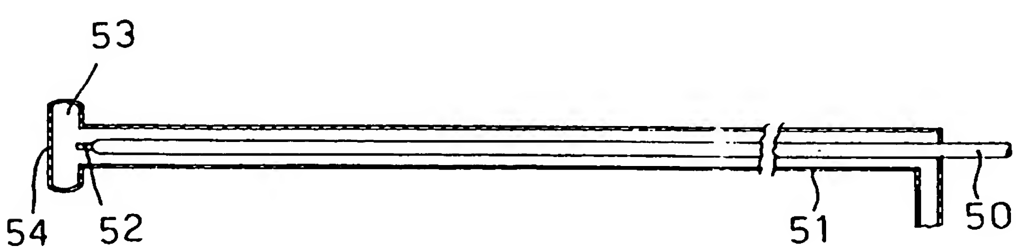

FIG. 4b

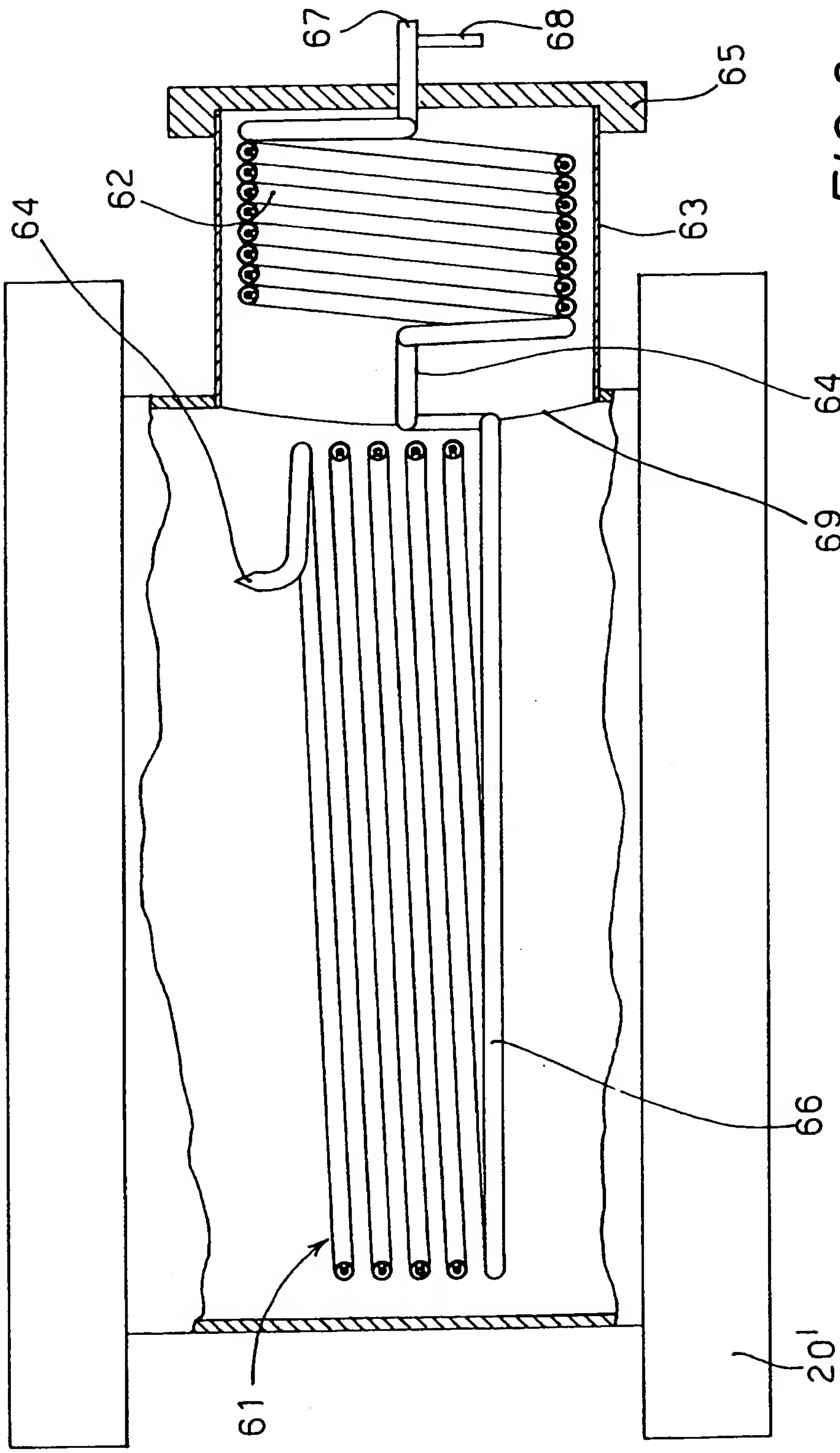

FIG. 3c

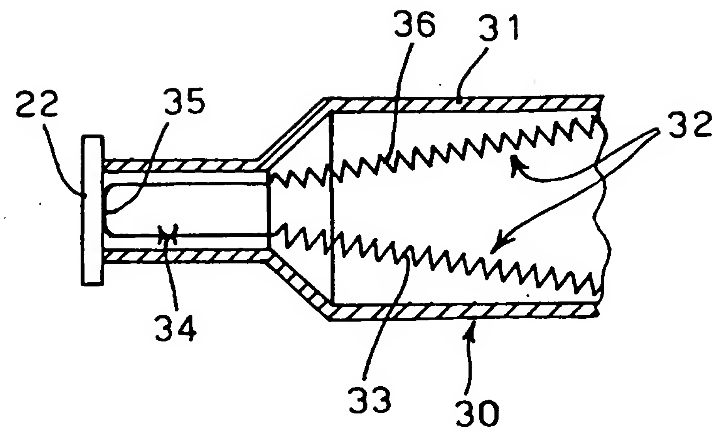
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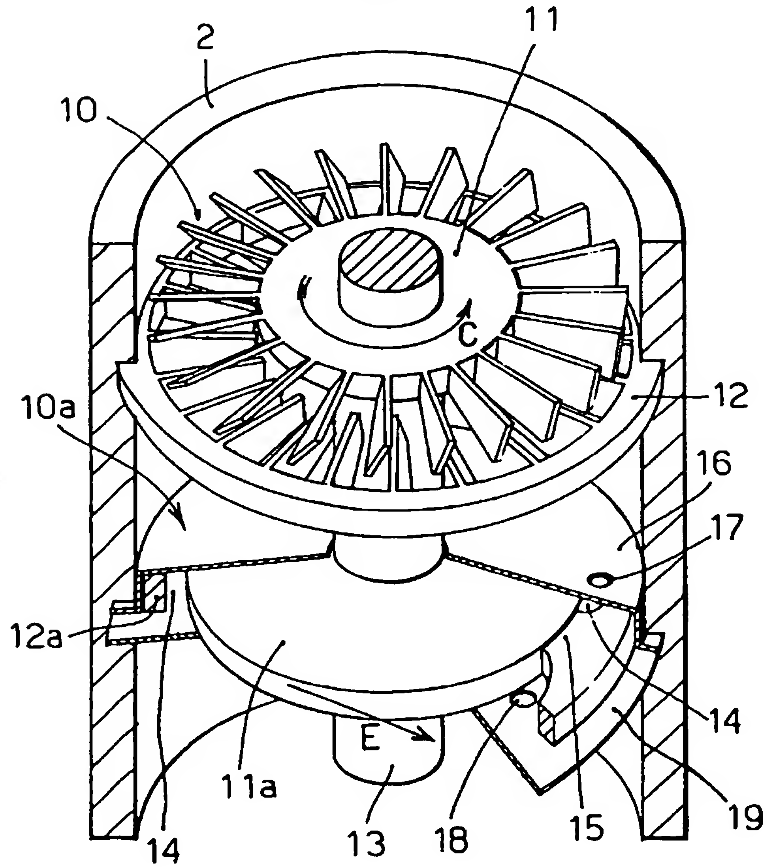
FIG. 4

FIG. 5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EUROPEAN SEARCH REPORT

Application Number
EP 97 10 5458

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 610 666 A (APPLIED MATERIALS) * the whole document * ---	1-3,12	F04D19/04 F04B37/06 F04B41/06
A	US 5 483 803 A (MATTÉ) * the whole document * ---	1,3,11,12	
A	EP 0 332 107 A (KABUSHIKI KAISHA TOSHIBA) * the whole document * ---	1,3,6,7,12	
A,D	US 5 062 271 A (OKUMURA) * the whole document * ---	1,3,6,7,12	
A,D	US 5 337 572 A (LONGSWORTH) ---		
A,D	US 4 926 648 A (OKUMURA) ---		
A,D	EP 0 445 855 A (VARIAN) -----		

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
F04D F04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 October 1997	Teerling, J

CATEGORY OF CITED DOCUMENTS

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